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FINAL REPORT

SOME FACTORS AFFECTING MECHANICAL PROPERTIES OF LODGEPOLE PINE FLAKE LUMBER

COOPERATIVE AGREEMENT 22-G-6-INT-44

DEVELOPMENT AND EVALUATION
OF NEW TECHNOLOGICAL CONCEPTS AND PRACTICES
FOR MORE EFFECTIVELY UTILIZING LODGEPOLE PINE:

PHASE II

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SOME FACTORS AFFECTING MECHANICAL PROPERTIES OF LODGEPOLE PINE FLAKE LUMBER

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and
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INTRODUCTION

Lodgepole pine (principally Pinus contorta var. latifolia Engelm.) occupies about 13 million acres of commercial forest land in the United States--mostly in the Intermountain West. Perhaps half of this volume in the Intermountain West is found in trees 6 inches d.b.h. or smaller, currently eliminating utilization as structural lumber as a forest management alternative.

This experiment was designed to provide the preliminary information required to produce structural lumber of lodgepole pine flakes. In order to have structural properties competitive with solid lumber, lodgepole pine flake lumber at 10 percent moisture content should have a design stress in static bending of 2000 psi and a modulus of elasticity of 1,500,000 to 2,000,000 psi. Since most sawn structural lumber has a finished thickness of 1.5 inches, this study's specimens were manufactured in the actual dimensions of 2 by 4's currently on the market.

The experiment was designed to investigate the effects of flake thickness, adhesive solids content, flake raw material specific gravity, compaction ratio, and type of flake on the modulus of elasticity, maximum crushing strength and flake lumber specific gravity.

Flake thickness variation has been shown to produce flakeboard of different properties (Koch, 1972; 1985), and was a principal factor to be studied in this experiment. Flakes were machined in three average thicknesses, 0.015-, 0,022- and 0.030-inches. These thicknesses are representative of the range encountered in the industry, and sufficiently diverse to provide significant differences in properties (Koch, 1972; 1985).

Flake type has also been shown to affect flakeboard properties. Price and Kessler (1974) have shown that the uniform-width-and-thickness flakes made from engine-lathe-turned flakes produce products that are excellent standards for comparison. Their research showed engine-lathe flakes to make flakeboard with superior mechanical properties than flakeboard made with flakes manufactured with a shaping-headrig lathe or other industrial flake types. The reason for this superior performance was attributed to the veneer flake's greater width and thickness uniformity.

Compaction ratio has also been studied with results predictably showing that increasing compaction ratios provide higher internal bond, MOE-bending and MOR-bending values (Koch, 1985). This study investigated the effects of compaction ratio at three levels, with the largest, 1.6, being the highest compaction ratio that was attainable with the equipment available.

Many studies have investigated the effects of resin content on the properties of composite wood products (Koch 1972; 1985).

Resin contents of 4 and 8 percent have been shown to be the lower and upper limits, respectively, of the range showing the greatest affect on mechanincal properties. Below the 4 percent value, board properties are below an appropriate level, while increasing the resin content above the 8 percent level brings minimal increases in MOE and MOR and lowered internal bond strength because of excessive moisture content (Hse, 1975a).

Wood specific gravity has also been shown to affect flakeboard mechanical properties when panel density was held constant. In general, raw material of lower specific gravity produced higher-strength boards due to higher flake compaction and better surface contact of the flakes (McMillin, 1971; Hse, 1975b). The range of the the specific gravities in these studies, however, was quite large (0.45 to 0.53 and 0.38 to 0.63) while the range of specific gravity (oven-dry weight and green volume basis) of lodgepole pine in Montana would most likely range between 0.38 and 0.42. In order to provide a realistic view of the effect of the raw material's specific gravity on flake lumber properties, two raw material groups with specific gravities at the extremes of this range were selected for use in this experiment.

The original study plan also called for the construction of a laboratory press for producing 72-inch-long specimens in the second phase of the project to be conducted after results of this first phase were available. The cost of the first phase was much higher than estimated due to the cost of shipping materials from the Southern Experiment Station laboratory in Pineville, LA. The

costs of designing and building a press capable of producing the specific pressures needed to achieve the high compaction ratios likely to be used in manufacturing the flake lumber also exceeded the original estimates.

METHODS AND MATERIALS

In order to effectively study the effects of flake thickness, method of manufacture, raw material specific gravity, resin solids content and compaction ratio, the study was designed as a full factorial factorial experiment with three replications of every combination of these factors. The effects of these factors were then statistically analyzed, then graphically displayed in such a way as to separate factor combinations showing significant differences. Each phase of the experimental procedure will now be described and discussed.

Raw Material Selection

The assessment of the effects of specific gravity on flake lumber mechanical properties required more than 1,000 pounds (green weight) of lodgepole pine stem sections with two specific gravity means. The greater mean (0.42) represented the high-end, while the lesser (0.38) represented the lower end of the mean specific gravity range for trees grown in the United States (Koch, 1987). Trees were harvested from two western Montana sites: the School of Forestry's Lubrecht Experimental Forest, 30 miles east of Missoula, and the Deerlodge National Forest, 70

miles southeast of Missoula. More than 50 trees were initially selected from each location on the basis of absence of outward signs of decay such as fruiting bodies, catfaces, and bark beetle infestation and eccentric stems which would indicate the presence of compression wood.

Open-grown lodgepole pine has been shown to be able to produce wood with low specivic gravity when radial growth rates approach 4 rings-per-inch (Burke,1987). The Lubrecht Forest contains a few stands of lodgepole pine growing in open, park-like configurations, that would provide trees with excessively-high growth rates (3-4 rings-per-inch) and relatively low specific gravity.

Conversely, the stemwood of slow-growing trees (30-40 rings-per-inch) from dense stands typically has relatively high specific gravity. The Anaconda-area stands were stocked at up to 1000 stems per acre, and provided 6 to 8-inch d.b.h., 180-year-old trees. More than 50 trees from this area were selected for specific gravity sampling,using the same stem form and defect-free criteria used with the Lubrecht trees.

Average tree specific gravity was estimated by extracting 0.25-inch increment cores at fifth-points along the length of the stems of several trees with diameters ranging from 6 to 10-inches at breast height. Following determination of the specific gravity of these trees by calculating the mean of the 5 samples, three trees of sufficient volume were selected from each location. Mean specific gravity for the Lubrecht trees was 0.381

with a standard deviation of 0.009. Specific gravity (green volume and oven-dry weight basis) for the Deerlodge trees averaged 0.0433 with a standard deviation of 0.011. Sections containing the live crown were generally not used due to lower specific gravity, nor were other sections of the trees showing defects including large knots and cat faces. Finally, the selected trees were cut into 48-inch bolts and end-coated with paraffin to prevent moisture loss prior to machining. Bolts selected for processing by shaping-lathe headrig were shipped to Pineville, LA, where the machining and drying was accomplished at the Southern Forest Experiment Station. Bolts selected for processing by the engine lathe were shortened to twelve inches in length, and stored under water treated with chlorine to prevent sapstain and mildew infection.

Flake Manufacture

Flakes for this experiment were made using two different processes; the shaping lathe headrig researched by Koch (1974) located at the Southern Experiment Station in Pineville, LA., and an engine lathe, commonly found in metal machine-shops, fitted with a wide head-knife and narrow trim knife that could produced continuous veneer in precise, adjustable widths.

The shaping lathe headrig flakes, further referenced as "lathe flakes" or "lathe", were machined in 3 nominal thicknesses: 0.015-, 0.022-, and 0.035-inches, and dried in the Southern Laboratory's dry kiln to an average moisture content of approximately 8 percent. After drying, the flakes were shipped

to Missoula and stored in sealed containers until use. Before glue application and mat formation, the flakes were brought to an equilibrium moisture content of 6 percent.

The flakes manufactured from veneer made with the metal lathe (referred to as "veneer flakes" or "veneer" in the rest of the report) utilized a lathe located at the University of Montana and veneer manufacturing head and flake cutter supplied by the Southern Station. The 3-inch-wide (longitudinal direction of the wood) veneer ribbon was then cut into flakes nominally 0.375" wide (tangential direction of the wood). The flakes were then dried on wire screens to an equilibrium moisture content of 6 percent and stored in sealed containers until use.

Both processes removed flakes from the bolts to a core diameter of 4-inches, thus limiting the amount of juvenile wood present in the flakes made from the fast-growing trees of low specific gravity taken from the Lubrecht site. Actual measurements of the dried flakes of both processes are shown in Table 1.

Adhesive Application and Mat Formation

Knowing the mean flake specific gravity, moisture content and mat volume allowed for the computation of the mat weight before adhesive application. This value was used to compute the required weight of mixed hot-setting phenol-formaldehyde adhesive to provide either the 5 or 8 percent resin solids content of the finished flake lumber. Compaction ratios used were 1.2, 1.4 and 1.6. Prior to adhesive application, the moisture content of the

furnish was determined using a moisture determination balance. Using this moisture content, the final solids content of the adhesive was adjusted by addition of water in order to provide the correct percentage and moisture content of the furnish

Table 1. Average dry measurements and standard deviations for veneer and lathe flakes.

Nominal Size (in.)	Length (in.)	Width (in.)	Thickness (in.)
	***** SHAPING LATHE HEADRIG FLAKES *****		
0.015	3.015 SD=0.008	0.397 SD=0.010	0.016 SD=0.0027
0.022	3.003 SD=0.005	0.388 SD=0.011	0.020 SD=0.0021
0.030	3.011 SD=0.010	0.392 SD=0.013	0.032 SD=0.0017
	***** VENEER FLAKES *****		
0.015	3.005 SD=0.006	0.369 SD=0.004	0.014 SD=0.0007
0.022	3.007 SD=0.005	0.373 SD=0.006	0.020 SD=0.0008
0.030	2.996 SD=0.009	0.370 SD=0.006	0.031 SD=0.0011

entering the press. Adhesive was applied to the furnish using a 42-inch diameter rotating tumbler and spray gun. Time required for adhesive application averaged 2.5 minutes. Target mat moisture content was between 9 and 10 percent.

After glue application, the raw mateial was weighed to provide the correct weight of furnish for the particular compaction ratio desired, and laid-up into a 6-inch by 10-inch mat with the long axis of the flakes oriented in teh long directon of the mat using a vibrating slot alignment device. The mat was formed between two aluminum transfer cauls and then placed between 0.5-inch-thick steel cauls, preheated to 250 degrees Farenheit. The assembly was placed in a hydraulic laboratory hot press, and pressed for 45 minutes at 500 psi and 350 degrees farenheit for 35 minutes (1.2 compaction ratio), 50 minutes (1.4 compaction ratio) and 70 minutes (1.6 compaction ratio). Due to these relatively long press times, excessive mat moisture and subsequent specimen blows at either resin content were not problems.

After removal from the press, the specimen blanks were cured at 130 degrees farenheit for 8 hours, and allowed to cool to room temperature prior to cutting a 3.5-inch wide by 6.0-inch long specimen for compression testing. After cutting to size, the specimens were allowed to come to an equilibrium moisture content of 6 to 7 percent. A total of 72 treatment combinations of the 3 compaction ratios, 3 flake thicknesses, 2 flake types, 2 wood specific gravities and 2 resin contents were produced. With three

replications of each treatment, the experiment utilized 216 specimens. Table 2 presents a complete description of the treatment combinations, and is used as a reference legend for Figures 1, 2, and 3.

Specimen Testing

Each specimen was tested in compression parallel to the flake alignment (long axis of the specimen) using the methods outlined in ASTM Standard D-143 (ASTM, 1972). The tests were conducted using a Tinius-Olsen, 60,000 lb. capacity, universal testing machine. A 4-inch guage-length compressometer was used to measure and record deflection to the nearest 0.0001 inches. with loads were recorded to the nearest 50 lbs.. After failure was achieved, which always appeared to be in tension perpendicular to the flake alignment axis, the specimen was sectioned into two pairs of sub-specimens for moisture content and specific gravity determination.

Dry-basis moisture content was determined using the oven-dry method, while specific gravity was gravimetrically determined using oven-dry weight and volume (measured by immersion).

Determination of Mechanical and Physical Properties

Modulus of elasticity (MOE), maximum crushing strength and specific gravity were determined using methods prescribed in ASTM Standard D-143. Modulus of Elasticity and maximum crushing strength were adjusted to 10 percent moisture content using the

method outlined in ASTM Standard D-2915.

RESULTS AND DISCUSSION

Table 2 lists all treatment combinations, and is used in conjunction with Figures 1, 2, and 3, which list the Modulus of Elasticity, Maximum Crushing Strength and Specimen Specific Gravity, respectively.

Mode of Failure

Failures in the lodgepole pine flake lumber specimens were almost always manifested by internal bond failures near the center of the pieces. However, in addition to the internal bond failures, a few of the specimens with compaction ratios of 1.6 also showed some spiral-collapse on the outside of the specimen, typical of those observed in solid specimens of lodgpole pine (Burke and Koch, 1986).

Maximum Crushing Strength

Figure 1 shows several treatment groups exhibiting similar effects on maximum crushing strength. The highest crushing strength values were obtained with a 1.6 compaction ratio, either type of 0.015-inch flake, 8 percent resin solids content and wood or either low or high specific gravity. The poorest results were obtained by using a 1.2 compaction ratio, 0.030-inch flakes of either type, 5 or 8 percent resin solids content, and wood of either specific gravity.

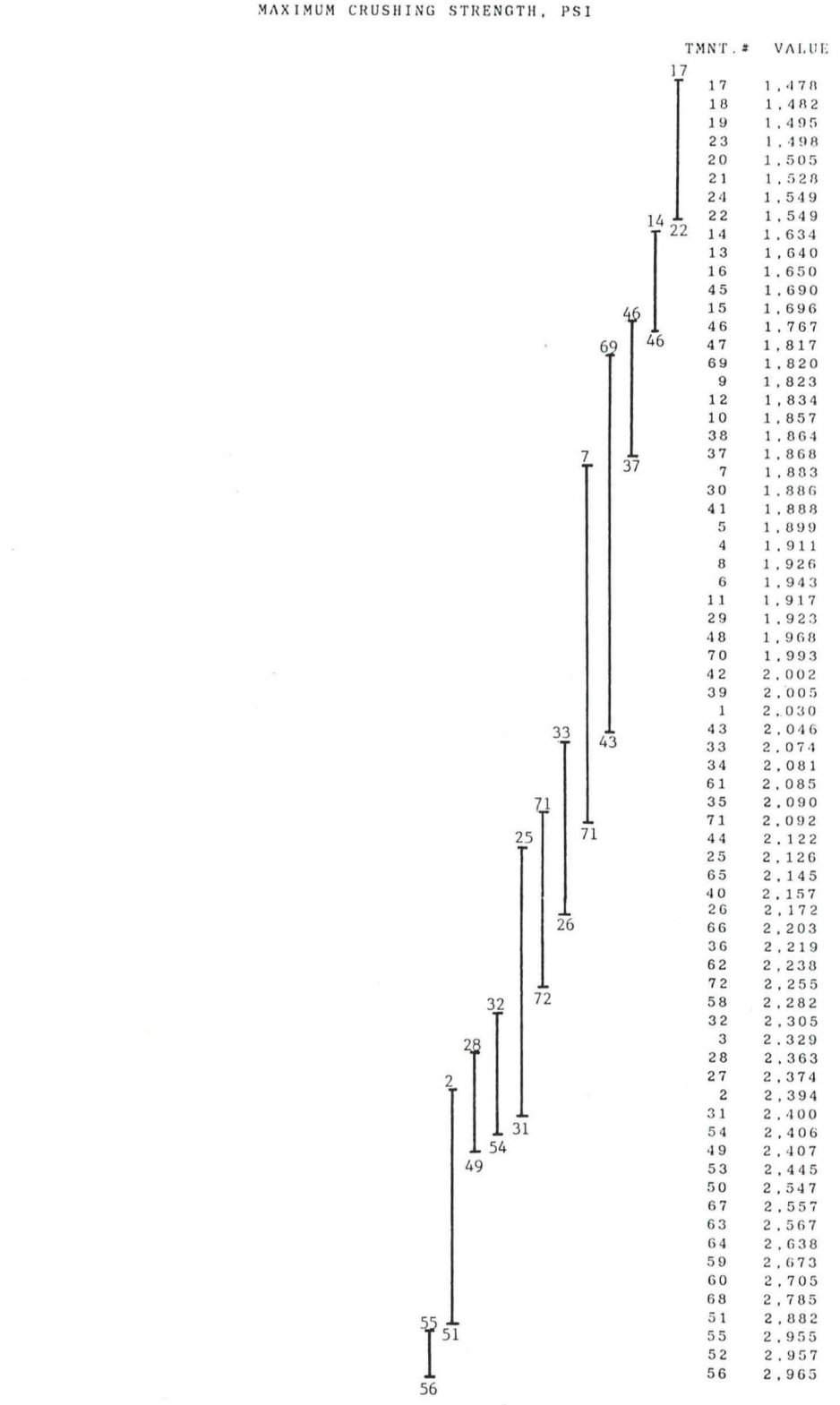
Table 2. Description of treatments with all factors identified.

Treatment #	Compaction Ratio	Flake Thickness (in.)	Flake Type	Resin Content (%)	Wood G
1	1.2	0.015	VENEER	5	0.38
2			VENEER	5	0.43
3			VENEER	8	0.38
4			VENEER	8	0.43
5			LATHE	5	0.38
6			LATHE	5	0.43
7			LATHE	8	0.38
8			LATHE	8	0.43
9		0.022	VENEER	5	0.38
10			VENEER	5	0.43
11			VENEER	8	0.38
12			VENEER	8	0.43
13			LATHE	5	0.38
14			LATHE	5	0.43
15			LATHE	8	0.38
16			LATHE	8	0.43
17		0.030	VENEER	5	0.38
18			VENEER	5	0.43
19			VENEER	8	0.38
20			VENEER	8	0.43
21			LATHE	5	0.38
22			LATHE	5	0.43
23			LATHE	8	0.38
24			LATHE	8	0.43
25	1.4	0.015	VENEER	5	0.38
26			VENEER	5	0.43
27			VENEER	8	0.38
28			VENEER	8	0.43
29			LATHE	5	0.38
30			LATHE	5	0.43
31			LATHE	8	0.38
32			LATHE	8	0.43
33		0.022	VENEER	5	0.38
34			VENEER	5	0.43
35			VENEER	8	0.38
36			VENEER	8	0.43
37			LATHE	5	0.38
38			LATHE	5	0.43
39			LATHE	8	0.38
40			LATHE	8	0.43

Table 2 (cont.). Description of treatments with all factors identified.

Treatment #	Compaction Ratio	Flake Thickness	Flake Type	Resin Content	Wood G
41	1.4	0.030	VENEER	5	0.38
42			VENEER	5	0.43
43			VENEER	8	0.38
44			VENEER	8	0.43
45			LATHE	5	0.38
46			LATHE	5	0.43
47			LATHE	8	0.38
48			LATHE	8	0.43
49	1.6	0.015	VENEER	5	0.38
50			VENEER	5	0.43
51			VENEER	8	0.38
52			VENEER	8	0.43
53			LATHE	5	0.38
54			LATHE	5	0.43
55			LATHE	8	0.38
56			LATHE	8	0.43
57		0.022	VENEER	5	0.38
58			VENEER	5	0.43
59			VENEER	8	0.38
60			VENEER	8	0.43
61			LATHE	5	0.38
62			LATHE	5	0.43
63			LATHE	8	0.38
64			LATHE	8	0.43
65		0.030	VENEER	5	0.38
66			VENEER	5	0.43
67			VENEER	8	0.38
68			VENEER	8	0.43
69			LATHE	5	0.38
70			LATHE	5	0.43
71			LATHE	8	0.38
72			LATHE	8	0.43

Figure 1. Specimen treatments arranged in order of maximum crushing strength. Treatments and values spanned by a line are not significantly different at the 0.05 level.



All other treatments remaining constant, the specimens pressed at a compaction ratio of 1.2 exhibited the lowest maximum crushing strength, while those pressed at a 1.6 ratio yielded the highest vlaues. In general, veneer flakes gave significantly higher values than lathe flakes, with flake thickness inversely related to maximum compression strength. Strength values were generally higher in specimens with the higher resin solids content, but raw material specific gravity played no significant role.

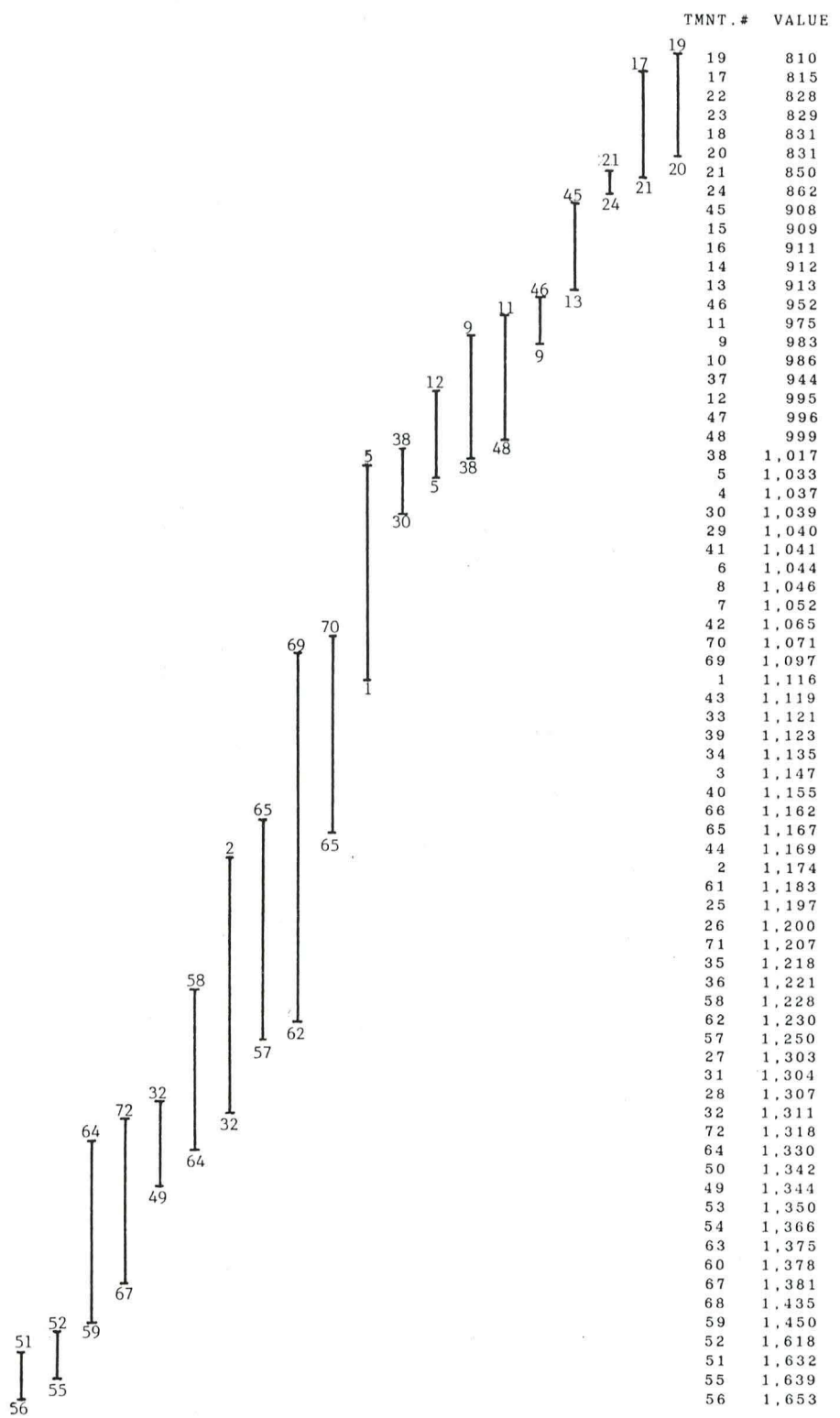
Modulus of Elasticity

Figure 2 shows several treatment groups exhibiting similar effects on modulus of elasticity. The highest values for modulus of elasticity in compression parallel to the flake axis were obtained by pressing at a compaction ratio of 1.6. Specimens using either flake type were found in the highest group, but flake thickness was limited to 0.015-inches. Resin content for the specimens in the highest-value group was 8 percent, and both the high and low specific gravity groups were represented.

The lowest values were obtained using a compaction ratio of 1.2 and 0.030-inch flake thickness. Flake type, resin content and raw material specific gravity were not significant factors in the specimens exhibiting low modulus of elasticity.

In general, compaction ratio, flake type and thickness, and, to a lesser extent, resin content, had significant effects on flake lumber modulus of elasticity.

Figure 2. Specimen treatments arranged in order of modulus of elasticity. Treatments and values spanned by a line are not significantly different at the 0.05 level.

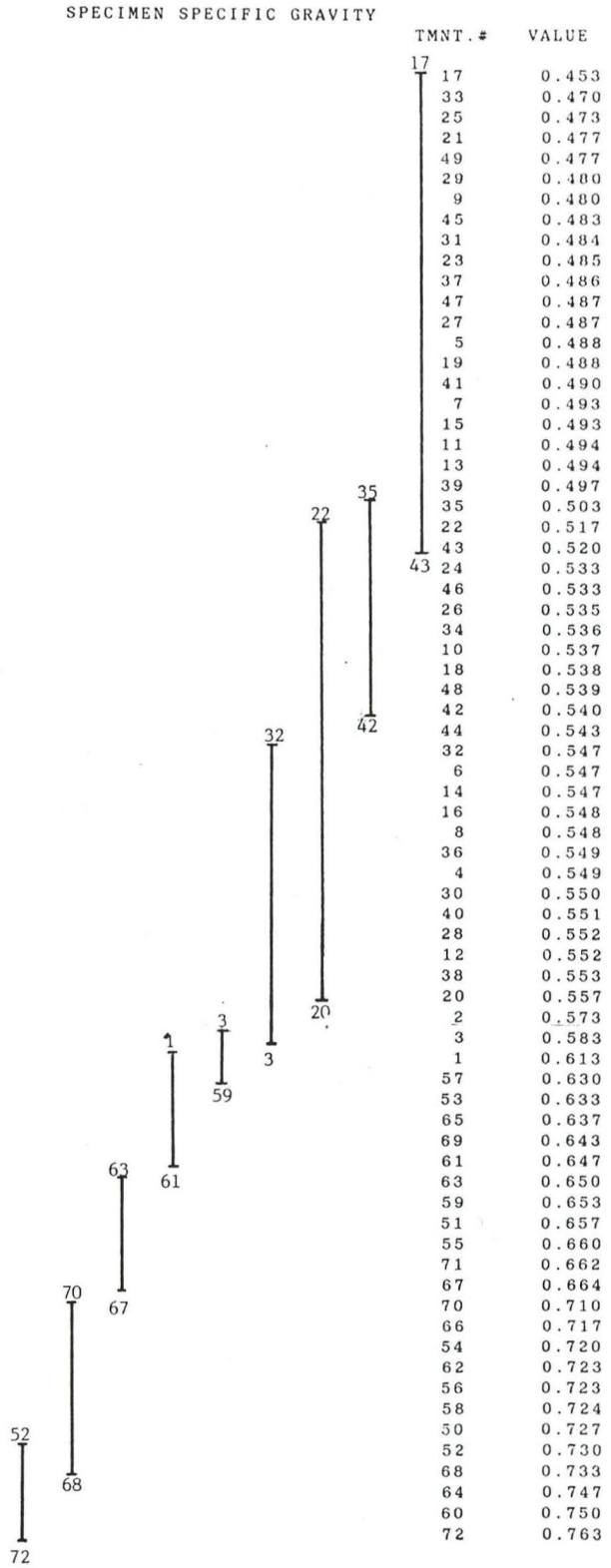


TMNT.#	VALUE
19	810
17	815
22	828
23	829
18	831
20	831
21	850
24	862
45	908
15	909
16	911
14	912
13	913
46	952
11	975
9	983
10	986
37	944
12	995
47	996
48	999
38	1,017
5	1,033
4	1,037
30	1,039
29	1,040
41	1,041
6	1,044
8	1,046
7	1,052
42	1,065
70	1,071
69	1,097
1	1,116
43	1,119
33	1,121
39	1,123
34	1,135
3	1,147
40	1,155
66	1,162
65	1,167
44	1,169
2	1,174
61	1,183
25	1,197
26	1,200
71	1,207
35	1,218
36	1,221
58	1,228
62	1,230
57	1,250
27	1,303
31	1,304
28	1,307
32	1,311
72	1,318
64	1,330
50	1,342
49	1,344
53	1,350
54	1,366
63	1,375
60	1,378
67	1,381
68	1,435
59	1,450
52	1,618
51	1,632
55	1,639
56	1,653

Specific Gravity

Figure 3 shows all treatments grouped by specific gravity. the highest values of flake lumber specific gravity were obtained by using a 1.6 compression ratio, either flake type, any flake thickness, 8 percent resin-solids content and the raw material with the higher specific gravity. The lowest values were obtained using a compaction ratio of 1.2, either flake type with thicknesses of 0.022- or 0.030-inches, 5 percent resin-solids content and raw material of low specific gravity. In general, compaction ratio, resin-solids content, wood specific gravity showed a positive relationship with specimen specific gravity. The type of flake did not significantly effect specimen specific gravity except for the 0.015-inch thickness, where specimens made from veneer flakes showed significantly higher specific gravity. Low density, 0.015-inch-thick flakes of both types pressed with 5 percent resin-solids content produced denser flake lumber than did 0.022- or 0.030-inch-thick flakes under the same conditions. The thinner flakes were more flixible and could be compressed into a more uniform-density specimen than could the thicker, and therefore,less flexible flakes.

Figure 3. Specimen treatments arranged in order of specific gravity. Treatments and values spanned by a line are not significantly different at the 0.05 level



CONCLUSIONS

The following conclusions can be made concerning the effect of compaction ratio, flake type and thickness, resin-solids content and raw material specific gravity on the maximum compression strength, modulus of elasticity in compression and specific gravity of flake lumber made from lodgepole pine.

1. Compaction ratio is a significant factor showing a positive relationship with all three measured properties for most treatment conditions, except those yielding the highest specimen stiffness.

2. Type of flake manufacture, veneer or shaping lathe headrig, has a significant effect on the modulus of elasticity of flake lumber.

3. Specimens made from veneer flakes, generally yield higher compression strengths and moduli of elasticity due to this flake type's more-uniform thickness and width. This increase in stiffness was only seen, however, at compaction ratios of 1.4 and 1.6.

4. Flake thickness generally showed a significant, negative relationship with maximum compressive strength and modulus of elasticity.

5. Resin-solids content showed a positive relationship with maximum crushing strength, modulus of elasticity and specific gravity.

6. Raw material specific gravity exhibited a positive influence on flake lumber specific gravity.

7. To maximize crushing strength and/or modulus of elasticity, flake lumber should be manufactured using a compaction ratio of at least 1.6, 0.015-inch-thick veneer or shaping lathe headrig flakes, 8 percent resin-solids content.

8. At the highest values for maximum crushing strength, wood specific gravity and flake type showed no significant effect on the maximum crushing strength.

9. To maximize end-product specific gravity, flake lumber should be manufactured using a compaction ratio of at least 1.6, 0.015-inch-thick veneer flakes, 8 percent resin solids and raw material from the high end of the range of lodgepole pine specific gravity.

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